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METHODOLOGY FOR EVALUATING AUTONOMOUS IR TRACKER PERFORMANCE

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ABSTRACT

Evaluating the capability of autonomous infrared (IR) trackers requires tools and methods to assess tracker performance as a function of target and background conditions. A methodology for assessing the performance of such IR trackers has been developed and implemented for analyzing captive flight test IR seeker imagery. Imagery is post-processed using the Tracker Analysis and Ground-Truth (TAG) tool to establish the target position in every frame of an IR sequence. The signature metrics of the target and background are extracted from each frame using the Software for Extracting Metrics from IR Sequences (SEMIRS). The sequences are then processed using the Imaging Seeker Algorithm Testbed (ISAT) to assess the performance of individual trackers. Finally, software has been implemented to match tracker performance results with the extracted signature information, producing a spreadsheet compatible file that can be used for analysis and plot generating. This process was developed and demonstrated using more than 50 IR sequences of a CFT IR seeker in closing encounters against ground vehicles.

1. Introduction

The evaluation of autonomous IR trackers has been ongoing for many years. Recent work at the US Army Aviation and Missile Command Research Engineering and Development Center (AMRDEC) has involved analyzing the performance of multiple IR trackers using Captive Flight Test (CFT) data. The desire has been to determine the correlation between tracker performance and target and background signature metrics. Dynetics and AMRDEC have derived a method for this type of analysis that is systematic and repeatable for any number of IR trackers or targets that need to be evaluated. Though developed for the application of evaluating CFT data, the methodology is applicable to evaluation of IR trackers using synthetic data.

Until recently, extracting the target and background signature metrics was a tedious, manually intensive process requiring many days to process a single sensor-to-target engagement. To overcome this, Dynetics developed the TAG tool to aid in ground-truthing IR image sequences (Reference 1). Ground-truthing is the process of identifying the target pixels in every frame of an IR sequence. The TAG tool allows ground-truthing entire sequences containing 4000 images in a matter of hours. The remainder of this paper will present the methodology and give some examples of its implementation.

2. Methodology for Evaluating IR Tracker Performance

The approach to evaluating IR tracker performance is shown in Figure 1. The process starts with the actual sequence of IR images taken from a CFT closing engagement of a seeker with a target. Also needed are the blackbody imagery and physical temperatures that are used for calibrating the imagery. Each of the individual steps of the methodology is addressed in the following subsections.

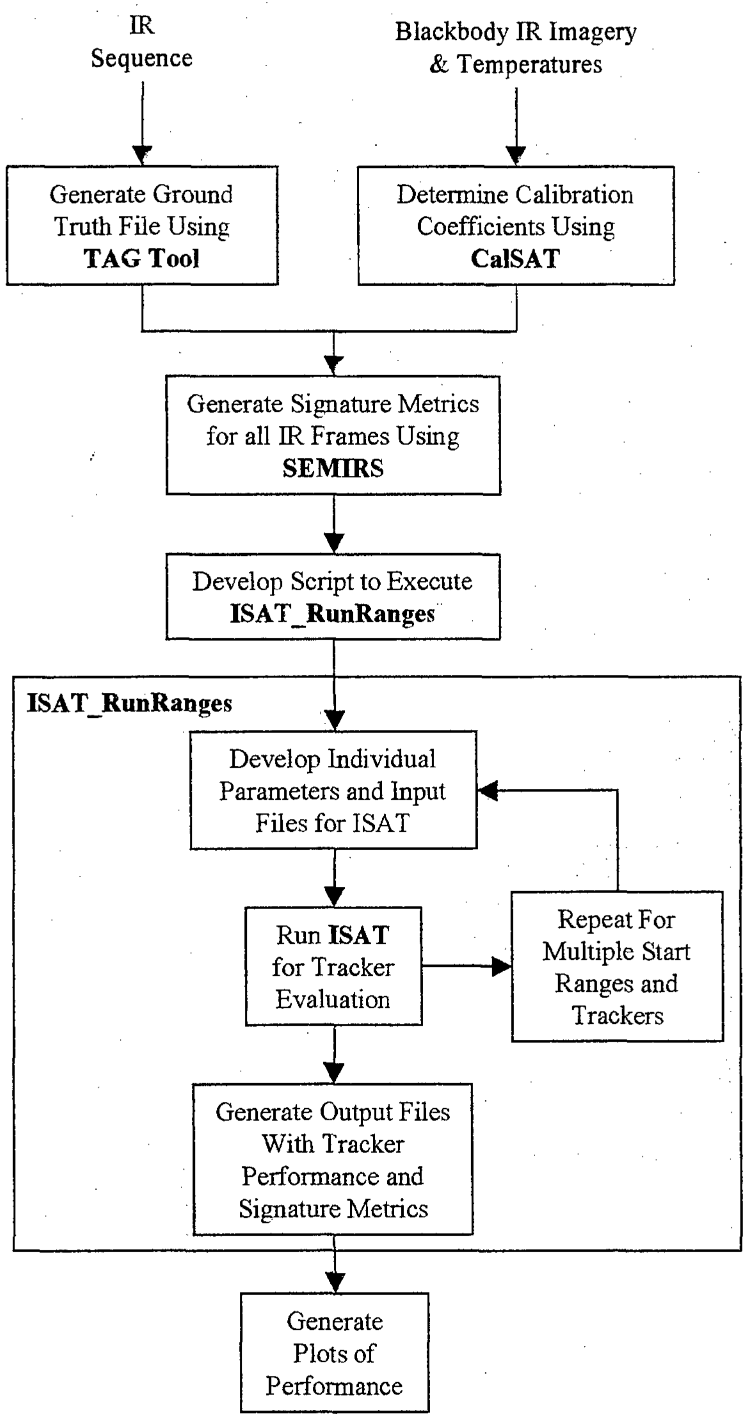


Figure 1. Methodology for Evaluating Autonomous IR Tracker Performance

2.1 Generating a Ground-Truth File

The process of generating a ground-truth file is an important step in evaluating an IR tracker. The ground-truth serves three purposes. The first is to target and background metrics in an automated fashion. The target pixels are identified within a rectangular box that a user defines using the TAG Tool. The second is to generate image stabilization information that can be used by the tracker in the event that there are large jerks from the gimbals in the CFT data. (The CFT data is typically collected open loop, and depending on the seeker gimbals, pointing joy stick, and seeker operator interactions, there can be inadvertent jerks in the seeker pointing.) The third purpose of the ground-truth is to enable automatic scoring of the IR tracker performance. This is accomplished by comparing the location of the IR tracker box to the ground-truth box.

Generation of the ground-truth for a single IR sequence comprising 4000 frames of data requires approximately 2-4 hours of time are required. The accuracy of the ground-truth box location and size is very important to the overall process including both the signature metrics extraction and IR tracker scoring. If the box is too big or is not centered on the target, then the target signature will be computed on a region that actually contains target and background. This same inaccuracy of the target box size or its placement will cause inaccuracies in the automatic scoring of the IR tracker. Figure 2 shows a ground-truth box that is appropriately sized and placed on the target.

To avoid these inaccuracies, great care is taken in generating the ground-truth using the TAG Tool. Often, the user will start ground-truthing the target location at the end of a sequence at which point the seeker was at its closest approach to the target. The user then typically steps backwards through the sequence, identifying the target in each image. As the target slant range increases and the target becomes smaller. the user is better able to precisely place and adjust the box over the target when performing this operation while stepping the IR images backwards. Reference 1 gives a complete overview of the TAG Tool and the steps for generating the ground-truth file.

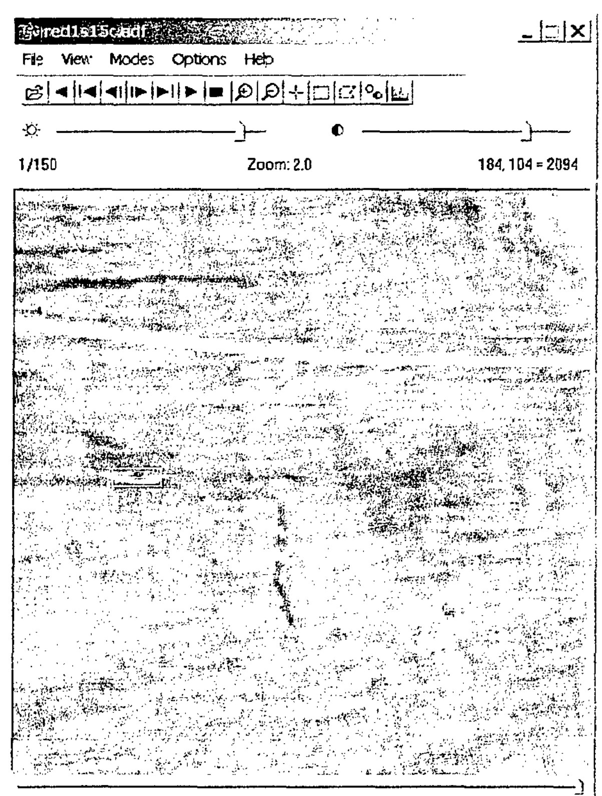


Figure 2. Example of Ground-Truth Box Placed on Target

2.2 Computing Calibration Coefficients

In order to compute signature metrics of the target and background, calibration information must first be determined. The typical process is to relate the IR image gray levels to temperature with a linear transformation. Over a small enough temperature range (20-30 K span), the linear fit is satisfactory for this transformation. The Calibrated Signature Analysis Tool (CalSAT) is used to generate a slope and intercept that transforms the individual pixels of an IR image into a temperature. Typically, the user imports an IR image with the four blackbodies for which the temperatures are known, as shown in Figure 3. The assumption is that the seeker viewed the blackbodies in the field during the CFT and close in time to the actual IR sequence to be analyzed. Also important is that the seeker digital imagery is stored without any automatic gain control adjustments to the data. Finally, a non-uniformity correction for a focal plane array seeker is necessary. CalSAT will compute the average gray level of each blackbody, and using the known temperatures of each, will compute a slope and intercept to transform the gray levels into temperature. The slope and intercept are stored in a file for later use.

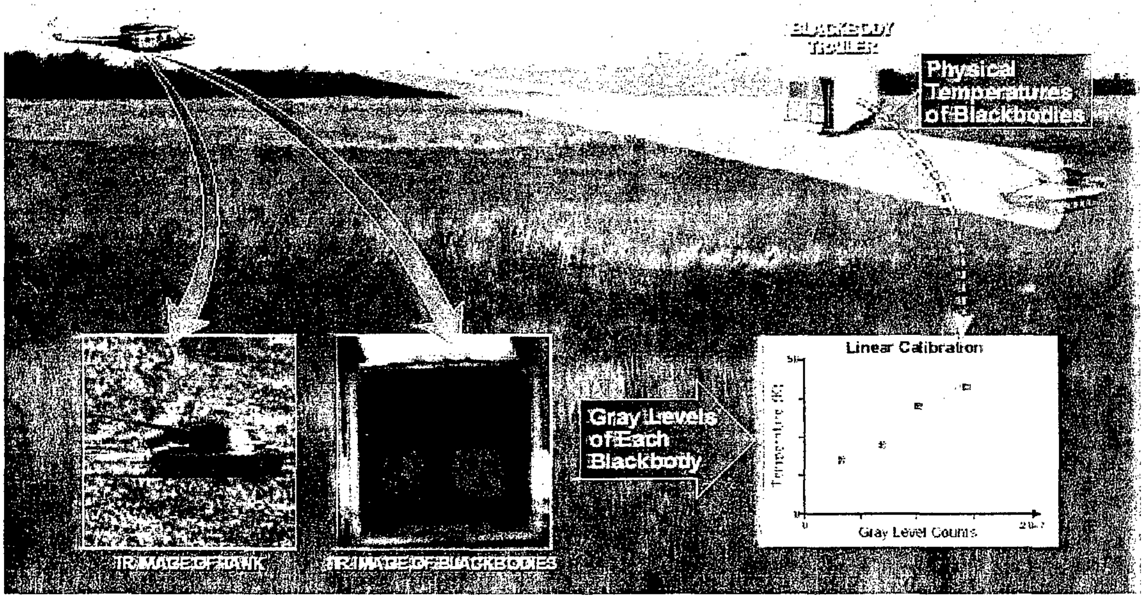


Figure 3. Test Range Scenario for Collecting Calibration Data

2.3 Generating Signature Metrics Using SEMIRS

The next step after generating a ground-truth file and calibration coefficients is to generate signature metrics for every image of the IR sequence. The Script for Extracting Metrics from IR Sequences (SEMIRS) was developed to accomplish this task. The inputs to SEMIRS are the IR sequence, its ground-truth file, and the calibration coefficients. SEMIRS then generates an output file containing many standard target and background signature metrics as shown in Table 1. In every case, the target region is defined as a rectangle (as discussed in the previous section) and the background region is an area that is twice as high and wide as the target area, centered on the target but excluding the target box. The metrics shown are apparent quantities, not source measurements, because this is typically what is of interest in assessing the IR tracker performance. SEMIRS is executed as a command line entry with associated arguments making it well suited for batch processing. Reference 2 gives a more in depth overview of the metrics shown in Table 1. Reference 3 gives more details on calibrating IR sequences and extracting signature metrics.

Table 1. Signature Metrics Computed by SEMIRS

Metric	Definition
$\overline{T}_{tgt}$	Average Target Temperature
σ_{tgt}	Standard Deviation of Target Temperature
N_{Tpix}	Number of Pixels in Target Region
M_{tgt}	Median of Target Temperature
$\overline{T}_{bkg}$	Average Background Temperature
σ_{bkg}	Standard Deviation of Background Temperature
N_{Bpix}	Number of Pixels in Background Region
M_{bkg}	Median of Background Temperature
ΔT	$\Delta T = \overline{T}_{tgt} - \overline{T}_{bkg}$
ΔT_{RSS}	$\Delta T_{RSS} = \sqrt{\Delta T^2 + \sigma_{tgt}^2}$
SCR_{RSS}	$SCR_{RSS} = \dfrac{\sqrt{\Delta T^2 + \sigma_{tgt}^2}}{\sigma_{bkg}}$
GLCM-TM	Gray Level Co-occurrence Matrix – Trackability Metrics

2.4 Running ISAT_RunRanges to Generate Inputs and Execute ISAT

The next step in evaluating the IR tracker is to execute a Perl script called ISAT_RunRanges. This script prepares the input files needed to run the IR tracker using the Imaging Seeker Algorithm Testbed (ISAT). ISAT is a software tool for design, development, and evaluation of acquisition and tracking algorithms developed previously by Dynetics for AMRDEC. The specific IR tracker under evaluation is added to and executed within the ISAT framework. An initial tracker box location is defined by the user after which the tracker autonomously determines where the target is on the next IR frame until the sequence is exhausted. For this specific application, the initial tracker box was taken from the ground-truth file. One newly added feature of ISAT is that it can automatically score the performance of the tracker by comparing the tracker box location to the ground-truth box. This is discussed in the next subsection. When a track is terminated either because the sequence was at its end or because the tracker lost track of the target, then ISAT writes out summary information. The ISAT_RunRanges script then uses this summary information to look up the corresponding signature metrics for the beginning and end of the run. It will also set up a new run at a closer slant range if the tracker failed to maintain track on the target throughout the entire run.

2.5 Automatic Scoring of the Tracker Performance

A metric was developed for assessing track quality or track error, and it is called "Instantaneous Track Error Metric – Overlap Error". It is based on the amount of overlap between the ground-truth and tracker boxes. Figure 4 shows a tracker box overlaid on a ground-truth box in an IR image with each region identified. The area (in pixels) for the truth region, tracker region, and overlap region are defined as NTRU, NTRK, and NOL, respectively. A ratio of NOL to NTRU gives an indication of the overlap compared to the ground-truth box. For the example in Figure 4, let us assume that this ratio is approximately 0.45, or there is 45% overlap between the tracker and truth boxes, as compared to the truth box. Another ratio between NOL to NTRK is defined to give some indication of how large the overlap region is compared to the track box, thus giving a measure of the size of the track box. For the example in Figure 4, let us assume that this ratio is 0.25, or there is 25% overlap between the tracker and truth boxes, as compared to the tracker box. If the track box is extremely large compared to the truth box, this second ratio will be much smaller than the first.

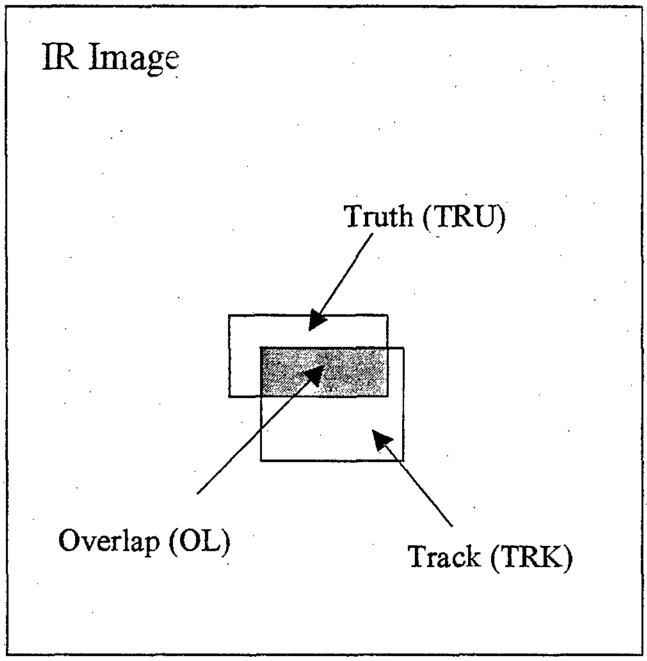


Figure 4. Track Box Overlaid on Ground-Truth Box in IR Image

Let us define each ratio as:

$$R_{TRU} = \frac{N_{OL}}{N_{TRU}}, \text{ and} \quad (1)$$

$$R_{TRK} = \frac{N_{OL}}{N_{TRK}} \quad (2)$$

By averaging the two ratios we can derive an instantaneous track quality metric as:

$$M_{TQ} = \frac{R_{TRU} + R_{TRK}}{2} \quad (3)$$

This metric has the desired characteristics that if the tracker box is exactly overlaid on and is the same size as the truth box, $M_{TQ} = 1$. If there is no overlap, the $M_{TQ} = 0$. To convert this metric into a "error" type metric where a "1" indicates maximum error and a "0" indicates no error, we can define an Overlap Error Metric as:

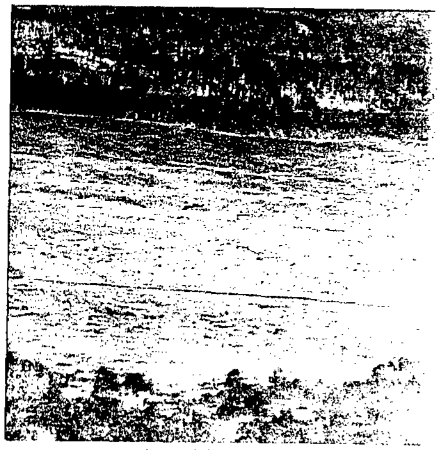
$$M_{OE} = 1 - M_{TQ} \quad (4)$$

As ISAT executes the tracker algorithm, it scores each individual IR frame using this overlap error metric. A criterion of M_{OE} of 0.95 or greater was chosen to indicate that the tracker was no longer tracking the target. If more that 10% of the total number of frames of the sequence exceeded this M_{OE} criterion, then the target was scored as "not tracked" by the tracker algorithm.

3. Example of Methodology

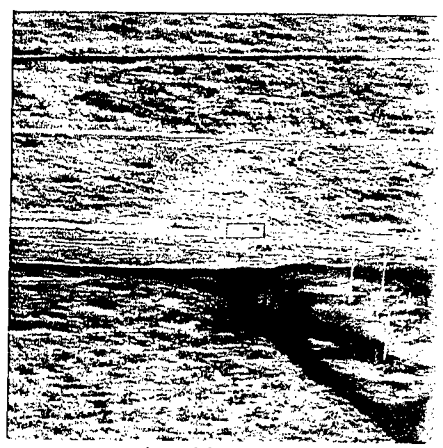
This section gives an example of using the methodology to evaluate an IR tracker performance against a T-72 tank. Imagery was collected from a captive flight test platform using an imaging IR seeker. The T-72 tank

was moving throughout the run and was being viewed by the seeker from a 270 degree target aspect. The tracker evaluated was a simple hot spot tracker. The initial track box is taken from the ground-truth data for this sequence, and the track was initiated at approximately 3,000 m slant range. Figure 5 shows representative images from the sequence at closing slant ranges with the ground-truth box overlaid on the target. The ground-truth box was generated using the TAG tool. Calibration was performed for this sequence using CalSAT along with a blackbody image and the known blackbody temperatures.

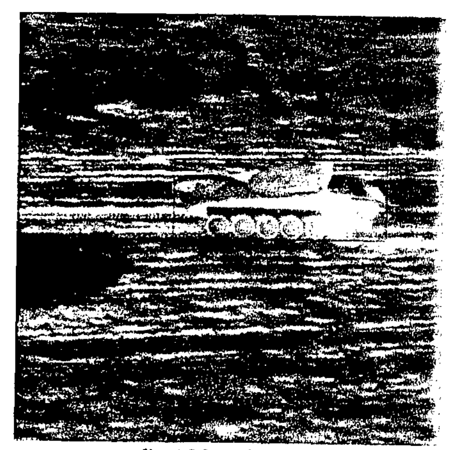


a) 3,000 m Range

b) 2,000 m Range



c) 1,000 m Range



d) 180 m Range

Figure 5. Representative IR Images of Closing Sequence at Various Slant Ranges

SEMIRS was then executed to extract the metrics for all of the IR frames of this sequence. Figure 6 shows a plot of ΔT_{RSS}, σ_{bkg}, and SCR_{RSS}. Note how the apparent ΔT_{RSS} increases as slant range decreases, as expected, because there is less atmospheric attenuation affecting the ΔT and there are more pixels on target which tends to increase σ_{tgt}. Figure 7 shows a plot of the target signature metrics including ΔT, σ_{tgt} , ΔT_{RSS}, and the number of pixels on target. The first three parameters are plotted using the left Y-axis, and the number of pixels is plotted using the logarithmic Y-axis on the right side of the plot.

Figure 8 shows a plot of the overlap error metrics (M_{OE}) as a function of range to the target. This demonstrates how well the hot spot tracker was able to keep the track box centered on the target. Given that the hottest portion of the target is the exhaust towards the rear of the tank, the tracker box was never completely centered up on the target, therefore there is always some overlap error. Figure 9 shows the tracker and ground-truth boxes for one IR frame of this sequence, demonstrating how the tracker centered its box on the hot exhaust, as expected.

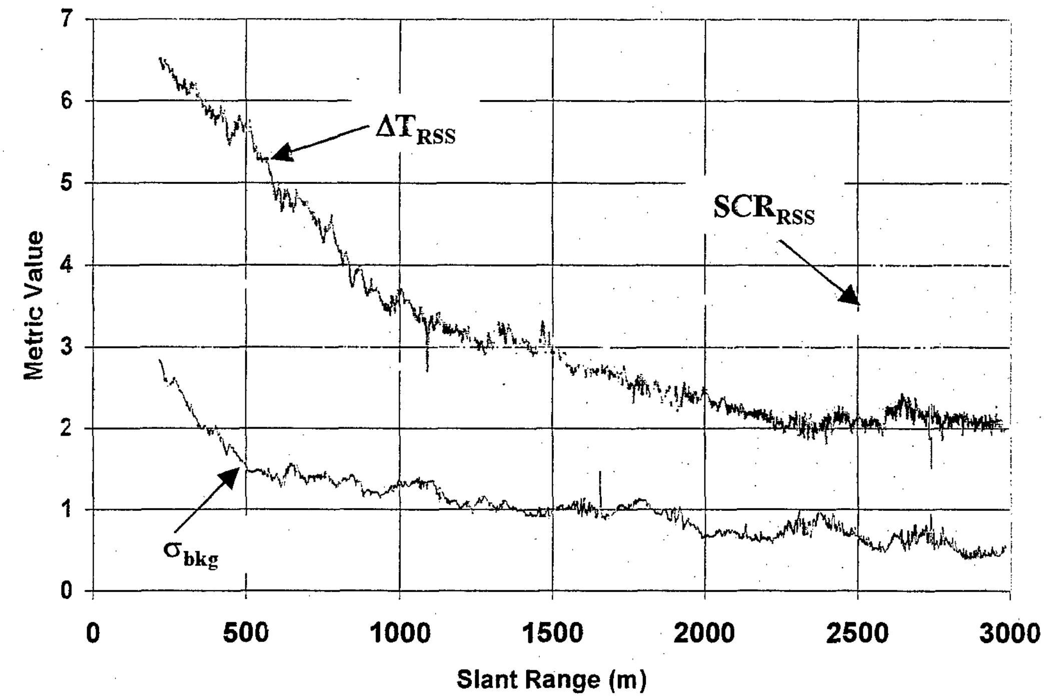


Figure 6. Contrast and Background Signature Metrics as a Function of Slant Range

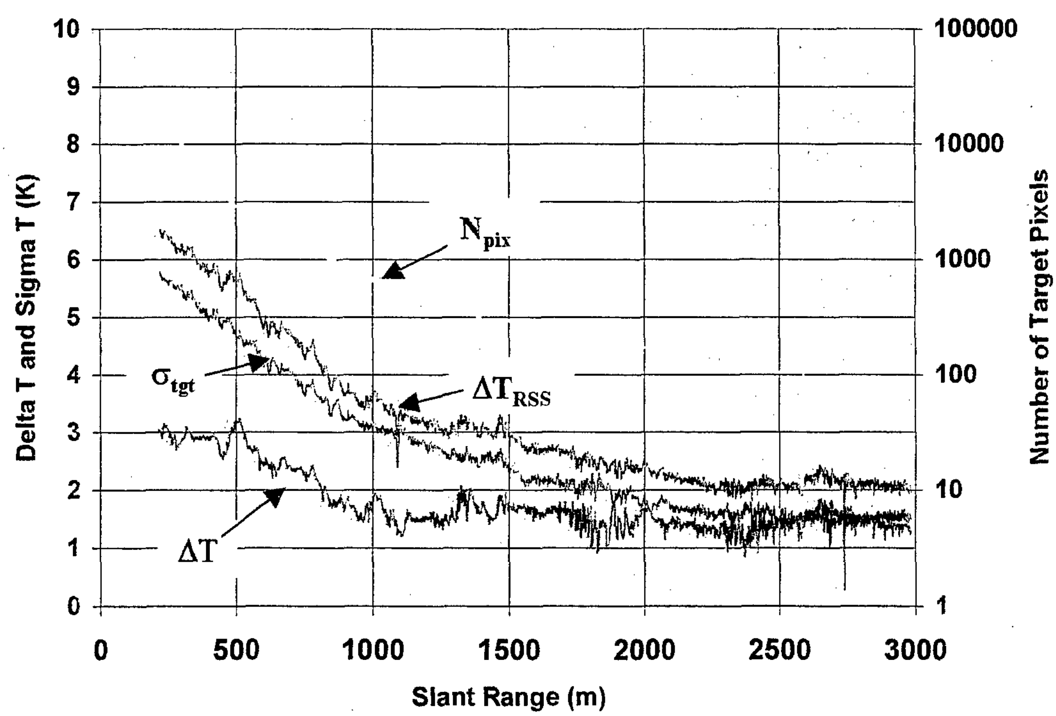


Figure 7. Target Signature Metrics as a Function of Slant Range

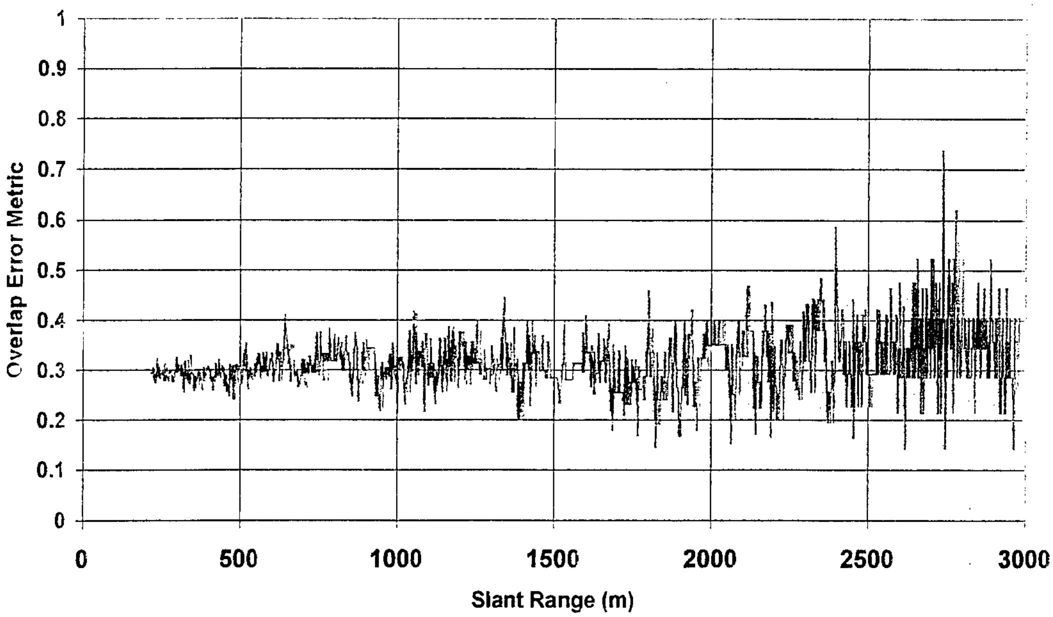


Figure 8. Overlap Error Metric (M_{OE}) as a Function of Slant Range

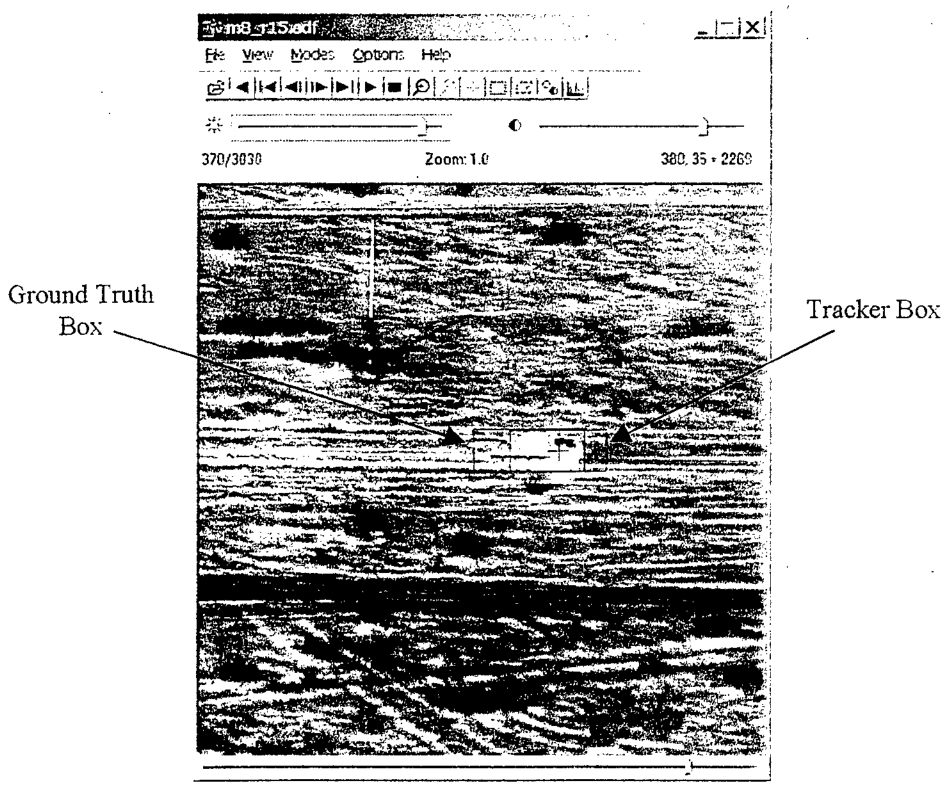


Figure 9. Tracker Box and Ground-Truth Box Placements

The ISAT_RunRange perl script accumulated the summary information shown in Table 2 for this particular sequence. The temperature metrics are in units of degrees Celsius. As a reminder, all values were computed as apparent quantities.

Table 2. Summary Signature Metrics at Beginning and End of Run

Metric	Beginning Value	Ending Value
$\overline{T}_{tgt}$	20.1601	30.8602
σ_{tgt}	1.5132	5.7718
N_{Tpix}	84	20436
$\overline{T}_{bkg}$	18.8259	27.8563
σ_{bkg}	0.4963	2.8030
N_{Bpix}	252	55486
ΔT	1.3342	3.0038
ΔT_{RSS}	2.0176	6.5067
SCR_{RSS}	4.0881	2.3213
GLCM-TM	0.8605	0.8375

By repeating this process for multiple seeker passes against an individual target, statistics of successful versus unsuccessful track attempts were accumulated. From this, analyses of signature metrics for successful tracks were compared to signature metrics for unsuccessful tracks.

4. Conclusions

The methodology presented in this paper was used to process over 50 different IR sequences collected during a CFT. The resulting data supported analysis of IR tracker performance as a function of target and background signature levels. Performance as a function of initial acquisition range was also derived from the data. The software tools were developed and enhanced to support the processing of a large volume of data in a relatively short period of time. The most labor-intensive portion of the processing is the ground-truth generation. Automation of the tracker processing and scoring was the key to completing the analysis on this large data set. The software tools developed by Dynetics for this particular type of analysis, including TAG tool, SEMIRS, CalSAT, ISAT, and ISAT_RunRanges, were crucial for automating as much of the process as possible.

5. Acknowledgements

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6. References

[1] Kimbel, Carrie, Jeff Todd, Paul D. Lavallee, Mark Chambliss, Jay Lightfoot, Jay Griffin, and Daniel Konkle, "Tracker Analysis and Ground-Truth Tool Description", Proceedings of the 2002 Ground Target Modeling & Validation Conference, 5-8 August 2002.

[2] Cannon, Lisa, Paul D. Lavallee, Mark Chambliss, and Eric Borg, "Signature Metrics for Imaging IR Seekers using Autonomous Tracking", Proceedings of the 12th Annual Ground Target Modeling & Validation (GTM&V) Conference, 7-9 August 2001.

[3] Lavallee, Paul D. and Mark Fowler, "Computing IR Signature Metrics Using Uncalibrated Field Test Imagery", Proceedings of the 12th Annual Ground Target Modeling & Validation (GTM&V) Conference, 7-9 August 2001.